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A NOVEL FLOATING OFFSHORE WIND TURBINE CONCEPT

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Abstract:

This paper will present a novel concept of a floating offshore wind turbine. The new concept is intended for vertical-axis wind turbine technology. The main purpose is to increase simplicity and to reduce total costs of an installed offshore wind farm. The concept is intended for deep water and large size turbines.
Keywords: offshore, floating, vertical-axis wind turbine, novel concept.

1. Introduction

Wind energy is more needed than ever. The offshore sector is in focus for development of larger and more cost effective projects. Horizontal-axis "state of the art" wind turbines have been erected on sea bed foundations in shallow water wind farms. Up-scaling of the wind turbines and positioning at deeper waters are in progress, and floating concepts at deep waters, like HyWind [1], Sway [2] and BlueH[3], are investigated. New ideas and innovative concepts may lead the way for further development of floating offshore wind turbines. Vertical-axis concepts are re-vitalized in offshore environments (eurowind [4] and NOVA [5]) and some of them are floating, like Ecopower [6] and SELSAM [7].
This paper deals with ideas of a novel floating offshore wind turbine concept which may point to future very large wind turbines in very large wind farms at deep waters. The basic ideas of the concept are described, and technical details of subcomponents and procedures for operation and maintenance are discussed. A vision regarding a future utilization of the novel concept is presented, and finally a status of the work done on the concept is made.

2. A novel floating offshore concept

In search of a simple and novel concept offering cost reduction potential in comparison to present horizontal-axis wind turbine applications, we have adapted technology elements known from vertical-axis wind turbines, floating offshore platforms, pultrusion, generators, power controls and wind turbine safety philosophy.
In particular, we suggest a vertical-axis concept consisting of a Darrieus rotor as the energy capturing device, and a long vertical rotating tube transitioning into a submerged buoy-like part which is connected to the sea bed (Figure 1).

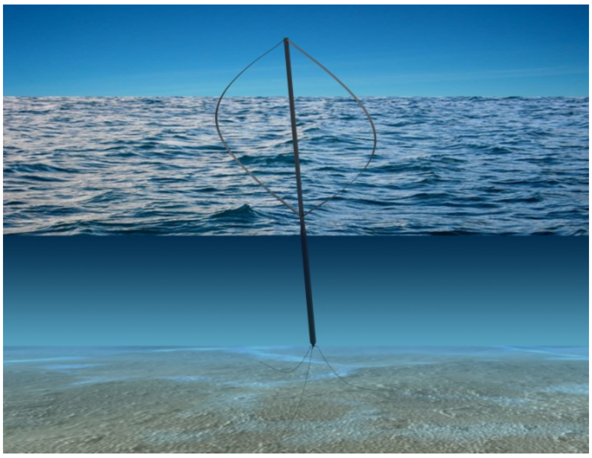

Figure 1 Artistic view of the concept

The concept combines:

- a 2 or 3 bladed Darrieus wind turbine rotor which does not need a yawing mechanism, neither a top-mounted heavy nacelle;
- an innovative offshore rotating foundation for deep-sea which does not need a main bearing;
- new technology in blade manufacture for large rotors;

- simple controls;
- simple safety philosophy.

3. Description of the basic components

Some specific technological solutions are proposed for the components of the turbine.

3.1 Rotor

The rotor is a vertical-axis wind turbine. Many different technical solutions have been proposed during the last 40 years, but we have chosen the Darrieus rotor. The mean reasons are: simplicity of the concept, reasonable efficiency, good economy, and a long record of research and development in the past.

3.2 Blades

The blades are characterized by a simple design (constant geometry along the length). The pultrusion process of GRP seems quite promising for large blade profiles, and the material strength of pultruded GRP is much better than for hand layed-up GRP for horizontal-axis wind turbines. It seems possible to design the rotor at a cost comparable to horizontal-axis wind turbines.

3.3 Transmission System

Many generator configurations are possible with the generator placed in the bottom of the submerged structure. The generator must in this case also be able to start the Darrieus rotor.
We see five potential configurations:

- The generator is mounted inside the submerged foundation at the bottom and rotates with the rotor. The shaft is extended through the foundation bottom and fixed to the torque arms, Figure 2a.

- The generator is mounted outside the foundation and fixed to the torque arms. The shaft is fixed to the torque arms (Figure 2b).

- The generator is fixed on the sea bed and the shaft is fixed to the rotating structure (Figure 2c).

- Two generators are placed in two turbine gondolas, fixed to the tubular structure. The turbine gondolas each consist of a turbine and a generator and through the rotation in the water they convert the rotor power into electricity (Figure 3).

- The conversion of the power can be obtained by a drag device, rotating slowly at the bottom of the structure, Figure 4. The configurations in Figure 3 and 4 both absorb the rotor torque in the water and torque arms are thus not necessary.

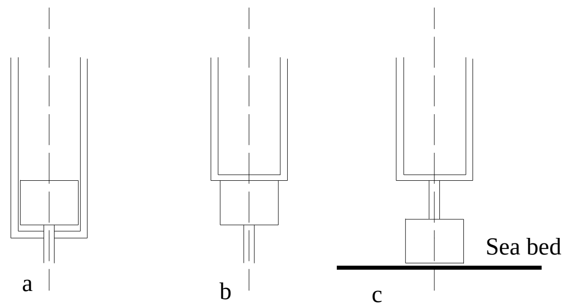

Figure 2 Different configurations for the placement of the generators

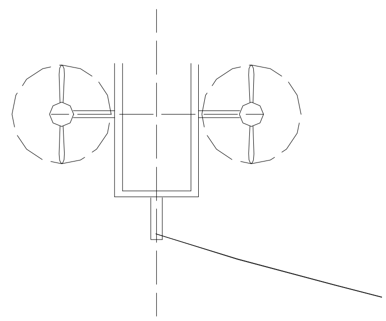

Figure 3 Configuration with two gondolas with turbines and generators

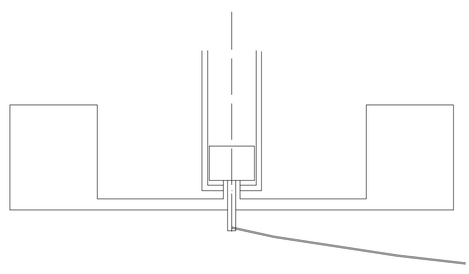

Figure 4 Drag device for torque absorption in the water

3.4 Safety System

Instead of air brakes we propose water brakes for overspeeding protection. The system consists of drag devices, that in overspeeding conditions are deployed from the rotating submerged foundation (Figure 5).

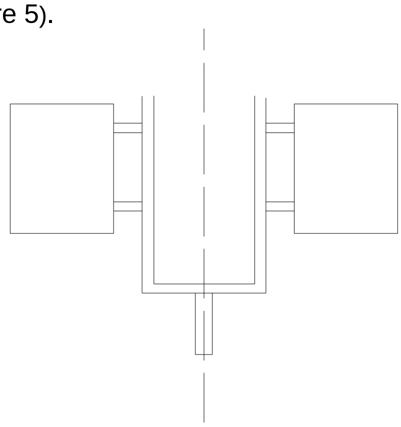

Figure 5 The safety system consisting of drag devices

3.5 Control System

The turbine does not need a pitch neither a yaw control system. The power control is obtained by rpm control of the rotor speed.

3.6 Anchoring Part

The torque and the thrust are transmitted through the foundation to the bottom of the structure. The foundation is anchored to the sea bed with tensioned wires. The forces are transferred through these wires. To take the torque two or more rigid arms are necessary (Figure 6).

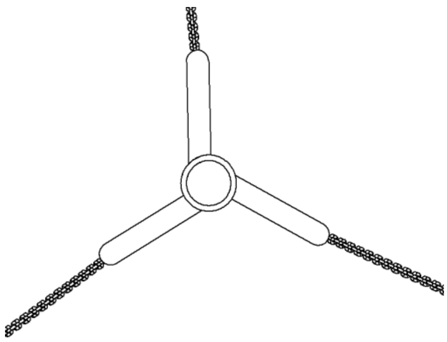

Figure 6 Torque arms and anchoring wires

3.7 Installation

The rotor and the foundation can be towed to the site. In case of a two-bladed rotor, the whole structure, without counterweight, can float and lay horizontally on the water line. Counterweight can be gradually added, to tilt down the turbine. In case that the generator is mounted inside the foundation, it can be inserted from the top of the structure.

3.8 O&M

Some specific solutions are available for the maintenance of the turbine. Moving the counterweight from the bottom of the foundation upwards is possible to tilt up the submerged part for service. An outside generator can be serviced and marine growths on the rotor can be removed. It is possible to place a lift inside the tubular structure to have easy access from the top of the turbine to the submerged part.

4. Advantages and challenges

The novel floating offshore wind turbine concept has some evident technical advantages, but on the other hand, some severe challenges are foreseen.

4.1 Advantages

The most obvious advantage of the concept is its simple design. The whole construction is simply a rotor, embedded in and supported by the water itself. The simple design is exemplified in the rotor tube which in principle can be made as one long tube like a wind turbine tower is made today. Another example of the simple concept is the blades. Rather large blade sections can be pultruded in GRP by production facilities that are indeed rather small. In principle, a production facility can be put on a ship, and the blades can be produced offshore in lengths of kilometres. The simplicity of the concept is underlined by the balancing of the forces in the water. The rotor is allowed to tilt, which makes it possible to transfer the rotor thrust to the shaft in the bottom from where it is further transferred to the seabed by anchor chains.

Another advantage of the concept is the simple way it can be regulated by the generator. The generator can start the rotor from stand still, regulate power by stall, and stop the rotor as a brake. It needs no yawing system to position the rotor into the wind, and it is not sensitive to inclined flow due to the tilting of the rotor, and no pitching of blades is necessary to regulate power. The Darrieus rotor is stall-regulated at high wind speeds, or the power can be down-regulated by reducing the rotor speed. Overspeeding of Darrieus wind turbines is a problem, but in this case the overspeed protection can be made with water brakes rather than with air brakes. Water brakes are much more efficient that air brake, which means that overspeeding protection can be made very and small.

An advantage of the concept is that the rotor may be tilted by moving the ballast in the tube. During installation and maintenance (3.7, 3.8)

The vertical-axis wind turbine concept seems to have an advantage for very large systems. The gravitational blade loads are the dominant fatigue loads for horizontal-axis wind turbines. They increase significantly with the increasing sizes, while the gravitational of vertical-axis turbines are constant during rotation.

4.2 Specific challenges

A number of challenges of the novel floating offshore design should be mentioned. First of all, the fundamental question whether the concept works properly according to the idea must be verified. The rotating foundation will have a certain friction with the water which will reduce the net amount of power. This friction will increase as marine growths build up on the surface. It is an open question whether this friction will increase to a significant amount or whether the friction can be kept low by reducing the biomass build up with ordinary bottom ship painting. At present, a silicone based paint, which significantly reduces the build up, is on the market.

The shaft sealing in the bottom of the rotor is also a challenge since the pressure difference over the bearings put high requirements to the sealing. Meanwhile, this technical problem is similar to the sealing problem of propeller shafts on sea vessels. It is therefore anticipated that solutions from shipbuilding or submarine construction technology building can be transferred to this wind turbine design.

The advantage that the generator with a high mass may be put in the bottom of the rotor tube generates another challenge. The positioning of the generator in the bottom makes maintenance and exchange of the component very complicated. Methods for lifting up the generator through the tube, eventually in smaller parts, must be developed. In case the generator is mounted outside the rotor, methods to tilt up the generator must be found.

Even though the Darrieus rotor was developed significantly during the 70's and 80's it is still considered a challenge to make blades for this design in a cost-efficient way. The most promising method seems to be pultrusion of GRP in full blade length sections that are bent into the blade shape and glued together. A substantial development work is needed to make such blades commercial compared to the horizontal wind turbine blades of today.

The most significant foundation difference compared to the horizontal-axis wind turbine is that the rotor torque must be absorbed in the sub-sea systems. This may be through the use of torque arms connected to the anchoring system or through drag elements in the water, either with turbine gondolas or drag plates. The torque of the Darrieus rotor varies with the position on the rotation and this varying torque will also have to be absorbed through the anchoring system. This additional dynamic effect has to be considered in the design.

5. Status of development

The concept emerged from a brain storming in 2007. A PhD study was initiated in August 2008.

5.1 Present status

First part of the PhD study has been to develop a vertical-axis rotor code. A double stream tube code has been implemented (in Fortran language) to provide some preliminary results. Some rough dimensions for two specific sizes have been determined, see Table 1.

Table 1 Dimensions and characteristics of 2 MW and 20 MW rotors

Size	2MW	20MW
Rotor Radius (m)	40	120
Rotor Height (m)	80	240
Chord (m)	2.5	11
Torque at rated power (N*m)	$5\ 10^7$	$1.4\ 10^6$
Thrust at rated power (N)	$2.5\ 10^6$	$2\ 10^5$
Rotational speed at rated power (rpm)	4.1	13.3

The submerged structure needs to be dimensioned for each of the two sizes. The submerged part has:

- To ensure the buoyancy to float
- To balance the weight of the structure and the vertical component of the thrust force.
- To ensure, with the counterweight, the equilibrium of the structure.

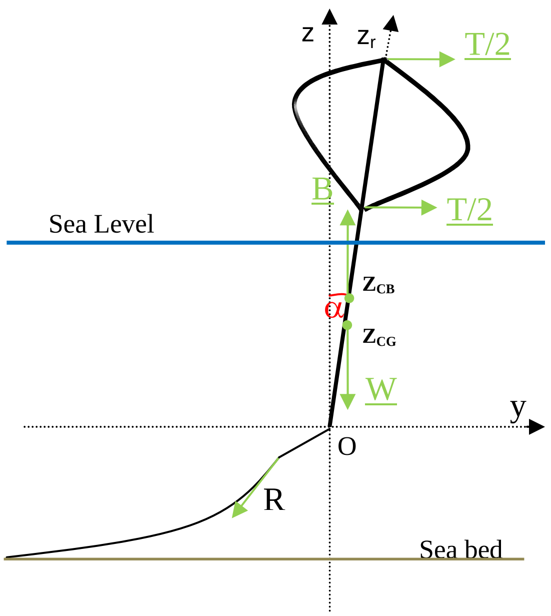

Figure 7 Schematic view of the forces

Particularly important is the position of the center of gravity with respect to the center of the buoyancy force. At equilibrium it is necessary that the center of gravity (z_{CG}) on the vertical-axis is below the center of buoyancy (z_{CG}). Figure 7 shows the forces, the external forces apply a moment on the structure. This moment has to be balanced from the moment due to the buoyancy:

$$M= (B-W)\ (z_{CG}-z_{CB})\sin(\alpha) \qquad (1)$$

where T is the thrust, B the buoyancy, W the weight and α the tilt angle.
A basic routine has been implemented to calculate the dimensions of the submerged part. The routine consider:

- The bending moment due to maximum value of the thrust and the tubular structure is dimensioned to a safety factor greater than two.
- Different materials (steel, aluminum, concrete) in order to optimize the total weight of the structure.
- The equilibrium between buoyancy force and weight.
- The equilibrium of the moment of the thrust and the moment due to buoyancy M (equation 1)
- A very simple design consisting of a slender tubular structure

Several design configurations are possible for the 2MW and 20MW sizes, see Table 2.

Table 2 Dimensions of the structure for 2MW and 20MW sizes

Size	2MW	20MW
Radius of the rotor structure (m)	2	3
Radius of the submerged part (m)	6	6.5
Thickness (m)	0.03	0.03
Total weight (tons)	2300	13000
Rotor length (m)	80	240
Total length (m)	161	345

5.2 Next Development

The next step in the technological development is the implementation of an aeroelastic and hydrodynamic coupled code. At Risø DTU a code has been developed for horizontal-axis floating turbines, HAWC2 [8]. The PhD project is ongoing to implement an aerodynamic subroutine for VAWT to HAWC2 . Indeed the equilibrium and the loads on a floating HAWC have been studied [9,10]. The influence of the rotation of the structure and of the cycling loads of a VAWT rotor is now being investigated.
Another subroutine to add is a subroutine to calculate the friction force around the rotating foundation. Preliminary studies indicate that this drag is insignificant (around 1% of the power). A more detailed analysis is needed, that includes other variables: influence of marine growths, change of roughness, current and waves.
In the meantime some future developments have been planned. In 2010 a kW size prototype will be built and tested in Roskilde fjord. This will be a concept test to verify the feasibility of the concept. A one year friction experiment will explore on friction and marine growths around a rotating cylindrical structure.
Looking forward (2011-2015), also an upscaling phase has been planned. A first demonstration project is planned with a turbine size in the order of 100kW. In the meantime feasibility studies of a MW scale turbine will go on a parallel track.

6. Commercial perspectives

Large scale wind energy systems at highly potent wind resource areas are key candidates for significant contributions to the energy supply. The most potent wind resource areas on the earth are deep sea offshore sites, and the potentially most interesting wind energy system for deployment at such sites are floating multi-MW size wind turbines. The primary markets are at deep sea offshore sites along the coasts of for example Norway, France, Spain, the Pacific and Atlantic

Ocean (USA) and Asia (China and Japan) and close to big cities. Along with development, optimized floating concepts could be commercialized for places like the North Sea or coastal shallow seas. On the long term exploitation of the wind resources in the "roaring forties" on the southern planet can be made possible with this concept combined with battery or hydrogen tankers that supports energy to coastal cities.

New business opportunities might enter the market in the marine operations and shipping sector, and in the shipyard industry. They will develop sea vessels accordingly with handling, manufacturing and operation of these large wind systems in mind:

- Ships with towing capacity and with pultrusion factory on board
- Shipping companies might trade electricity with battery ships gathering electricity from remote offshore wind farms.
- Floating factories might be developed for very large concepts (support structure for instance made with concrete composites)

The new concept contributes significantly with added value of technology to the wind industry if the concept is developed and demonstrated under real conditions. Within this perspective, the new concept may become an interesting competitor to concepts like HYWIND[1], SWAY[2], BLUEH[3] and NOVA[5], presently being closer to demonstration.

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